Physical and Mechanical Properties of Some Common Nigerian Timber Species Based on Limit State Design Approach

Abubakar I.[1], Nabade A. M.[2]

[1] Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria
[2] Department of Civil Engineering, Waziri Umaru Federal Polytechnic, Birnin Kebbi, Nigeria

[1] idrcivil1@yahoo.com; [2]amnabade@gmail.com

Abstract

This paper was aimed at the determination of physical and mechanical properties of some common Nigerian timber species. The timber species considered were *Strombosia pustulata*, *Macrocarpa bequaertii*, *Nauclea diderrichii* and *Entandrophragma cyclindricum*. The physical properties of the selected timber species including moisture content and density were determined in accordance with EN 13183-1 (2002) and EN 408 (2003). Mechanical properties of the timber species were determined using both four and three point bending tests based on standards such as EN 408 (2003) and ASTM D193 (2000). Characteristic values of the material properties were determined in accordance with EN 384 (2004). Adjustments of the characteristic values of mechanical properties and density of the selected timber species were made to the equivalent moisture content of 18% in order to suit the Nigerian environmental condition (NCP2, 1973). The least values of the mechanical properties obtained from the two above mentioned standards were considered.

Keywords

Eurocode 5; Limit State; Mechanical Properties; Nigerian Timber Species; Physical Properties

Introduction

Timber has been used as a building material for over 400,000 years. It is the most common and best-known material for house construction including framing of floors, walls and roofs. In Nigeria, the roof structures and ceiling noggins of most buildings are constructed from timber (RMRDC, 1998).

Timber, a natural and renewable material, has a high strength-to-weight ratio and is easy to work with (Apu, 2003); thus it has become one of the most widely used materials and has been found in large quantities in Nigeria. There are many types of softwoods and hardwoods in the country. The flexible use of timber in construction of buildings especially in roof fabrication has made it famous and popular construction material.

The exact quantity of wood and non-wood forest products in Nigeria cannot be easily estimated (Alamu and Agbeja, 2011). However, studies have shown that forest reserves occupy about 10 million hectares in Nigeria, which accounts for about 10% of a land area of approximately 96.2 million hectares (NPC, 2006; Alamu and Agbeja, 2011).

NCP2 (1973) is the standard used in design of timber structures in Nigeria since 1973 based on permissible stress design principles. The major content of the code was extracted from BS 5268 (2002); formerly CP112 (1967). Today, the replacement of BS 5268 (2002) with a limit state code; EN 1995-1-1 (2004) has mandated the revision of NCP2 (1973) to consider timber design in Nigerian construction industry designed in accordance with the limit state approach.

The physical and mechanical properties of Nigerian timber species as contained in NCP2 (1973) were based on the permissible stress design principles. The strength classes for Nigerian timbers according to NCP2 (1973) ranges from the highest grade N1 to the weakest grade N7. The physical and mechanical property values decrease from N1 to N7. The major applications of timber in Nigerian construction industry are in roof fabrication, formwork construction, footbridges, as railway sleepers etc. High grade timbers with high mechanical property values are used as railway sleepers or construction of formwork in order to support concrete deck.

Strength classification of timber in accordance with the EN 1995-1-1 (2004) design principles was based on the moisture content (MC) of 12% whereas the current Nigerian code of practice specified an MC of 18% for design purpose. It is therefore necessary to review the properties of Nigerian timber species (NCP2, 1973) in

accordance with the EN 1995-1-1 (2004), in order to suit the Nigerian environmental condition at MC of 18%.

The current study considered the determination of physical and mechanical properties of *Strombosia pustulata*, *Macrocarpa bequaertii*, *Nauclea diderrichii* and *Entandrophragma cyclindricum* timber species from experimental works.

Material and Methods

Materials

The materials used in this study are timber specimens obtained from Ekiti State in the southern part of Nigeria: *Strombosia pustulata, Macrocarpa bequaertii, Nauclea diderrichii and Entandrophragma cyclindricum.*

For bending strength and Modulus of Elasticity (MOE) tests, 160 No. beams of 50 mm×75 mm×1500 mm each, that is, 40 pieces per specie were prepared with the aid of sawing and milling machines. For MC and density, 60 No. slices of 50 mm×75 mm×50 mm each were prepared at the carpentry workshop of the Department of Civil Engineering, Ahmadu Bello University (ABU), Zaria, Nigeria.

Methods

The physical properties of the selected timber species were determined in accordance with EN 13183-1 (2002) and EN 408 (2003). The mechanical properties were however determined in accordance with EN 408 (2003) and ASTM D193 (2000). The characteristic values of material properties (i.e. mechanical properties and density) of the timber species were determined in accordance with EN 384 (2004). From the results of the characteristic values of mechanical properties, the minimum values were recommended based on the specification of EN 384 (2004).

Moisture content (MC) and Density

The species moisture contents (MCs) were determined in accordance with EN 13183-1 (2002) and EN 408 (2003). The MC for each slice was determined by first measuring its initial mass before drying using weighing balance. The test slices were then oven dried at a temperature of 103 ± 2^0C for 24 hours. The initial and oven dry mass of each slice were recorded and the MC was then computed from equation 1:

$$MC = \frac{m_1 - m_2}{m_2} \times 100\% \qquad (1)$$

Where m_1, m_2 and MC are the initial mass, oven dry mass and MC of test slice respectively.

The density of wood is its mass per unit volume at a specified value of MC. The density of slice was determined in accordance with EN 408 (2003).

The characteristic values of density of specie were determined in accordance with EN 384 (2004) from equation 2:

$$\rho_k = \rho_{05} = \left(\bar{\rho} - 1.65s\right) \qquad (2)$$

Where ρ_k is the characteristic density, $\bar{\rho}$ and s are the mean and the standard deviation of densities of all slices (kg/m^3) respectively.

The 18% MC adjustment for characteristic density of timber specie as required by NCP2 (1973) was computed using equation 3:

$$\rho_{k,18\%} = \rho_w\left(1 - \frac{(1-0.5)(u-18)}{100}\right) \qquad (3)$$

Where $\rho_{k,18\%}$ is the characteristic density at 18% MC, ρ_w is the characteristic density at the MC during the bending test, (kg/m^3) and u is the measured MC, (%).

This study did not consider any MC higher than 18%.

Mechanical Properties of Wood

Mechanical properties are the characteristics of a material in response to externally applied forces including elastic properties which characterize resistance to deformation and distortion, and strength properties which characterize resistance to applied loads (Winandy, 1994).

Bending Strength

The four point and three point bending strength tests as specified by EN 408 (2003) and ASTM D193 (2000) were carried out on 40 specimens from each of the selected timber specie in the concrete and materials laboratory of the Department of Civil Engineering, Ahmadu Bello University (ABU), Zaria. Each specimen was tested using universal testing machine (UTM) until failure occurs. The failure load in respect of the individual beam was recorded.

The four point bending strength test was computed from equation 4 (EN 408, 2003):

$$f_m = \frac{aF_{\max}}{2W} \qquad (4)$$

Where a is the distance between loading position and the nearest support (mm), $F_{\max}$ is the maximum load (N), W is the section modulus (mm^3) and f_m is the bending strength (N/mm^2).

On the other hand, the three point bending strength

test was computed from equation 5 (ASTM D193, 2000):

$$f_m = \frac{3F_{\max} l}{2bh^2} \quad (5)$$

Where f_m is the bending strength (N/mm²), $F_{\max}$ is the maximum Load (in Newton), b is the width of cross-section in bending test (mm), h is the depth of cross section in bending test (mm) and l is the length of test specimen between supports (mm)

The three point bending test produces its peak stress at the specimen mid-point with reduced stress elsewhere. This stress localisation is ideal for testing specific isolation of stress on a component or material. While the four point bending test produces peak stresses along an extended region of the specimen. For the two methods of tests, the shear was not considered as it was negligible when compared to bending effect.

The characteristic values of strength properties based on the measured MC were computed from equation 6 (Ranta-Maunus et al., 2001):

$$f_{m,k} = 1.12 f_{05} \quad (6)$$

Where $f_{n,k}$ and f_{05} are the characteristic and 5th-percentile values of bending strength respectively.

According to EN 384 (2004) the sample size to be considered for bending test should have a depth of 150 mm. For depths other than 150 mm, the 5-percentile values of bending strength shall be adjusted to 150 mm depth or width by dividing by equation 6a:

$$\left[k_h = \left(\frac{150}{h} \right)^{0.2} \right] \quad (6a)$$

Where k_h is the depth adjustment factor and h is the depth adopted for the bending the test. As such, the 5-percentile values of the four species were adjusted using the equation 6a. A depth of 75 mm was adopted for the test (that is, h=175 mm).

The adjustment for characteristic values of bending strength from the measured MC to 18% MC in order to suit Nigerian environmental condition (NCP2, 1973) was computed from equation 7:

$$f_{m,18\%} = \frac{f_{measured}}{1 + 0.0295(18 - u)} \quad \mathbf{(7)}$$

Where $f_{m,18\%}$ is the characteristic bending strength at 18% MC, u is the measured MC (%) and $f_{measured}$ is the characteristic bending strength at the measured MC (*N/mm²*).

Modulus of Elasticity

The global MOE was derived from four point and three point bending tests as specified by EN 408 (2003) and ASTM D193 (2000). In determining the global MOE, load was applied at constant rate using Universal Testing Machine (UTM). The deflection of the beam corresponding to the load applied at constant rate was recorded. The global MOE of the individual beam derived from four point bending test was then computed from equation 8 (EN 408, 2003):

$$E_{m,g} = \frac{l^3 (F_2 - F_1)}{bh^3 (w_2 - w_1)} \left[\left(\frac{3a}{4l} \right) - \left(\frac{a}{l} \right)^3 \right] \quad (8)$$

where $E_{m,g}$ is the global MOE in bending, a is the distance between inner point loads and supports (mm), l is the length of the test specimen between the testing machine grips in bending test (mm), $(F_2 - F_1)$ is the increment load (in Newton) on the regression line with a correlation coefficient of 0.99 and $(w_2 - w_1)$ is the increment of deformation (mm) corresponding to $(F_2 - F_1)$.

On the other hand, the global MOE as derived from three point bending test was computed from equation 9 (ASTM D193, 2000):

$$E_{m,g} = \frac{l^3 (F_2 - F_1)}{48I(w_2 - w_1)} \quad (9)$$

where $E_{m,g}$ is the global MOE in bending, l is the length of the test specimen between the testing machine grips in bending test (mm), I is the second moment of area (mm⁴), $(F_2 - F_1)$ is the increment load (in Newton) on the regression line with a correlation coefficient of 0.99 and $(w_2 - w_1)$ is the increment of deformation (mm) corresponding to $(F_2 - F_1)$.

The characteristic values of MOE based on the measured MC were computed from equation 10 (EN 384, 2004):

$$\bar{E} = \left[\frac{\sum E_i}{n} \right] 1.3 - 2690 \quad (10)$$

Where E_i is the ith value of MOE, n is the number of specimens and $\bar{E}$ is the mean value of MOE in bending.

According to section 3.1 of EN 384 (2004), for MOE, the mean MOE is also a characteristic value. For this reason, mean MOE is equivalent to characteristic MOE (that is, $E_{m,k} \equiv \bar{E}$).

The adjustment for characteristic MOE of timber specie from the measured MC to 18% MC in line with NCP2 (1973) requirements was also made based on the characteristic values of sample. It was therefore

computed using equation 11:

$$E_{m,18\%} = \frac{E_{measured}}{1+0.0143(18-u)} \quad (11)$$

Where $E_{m,18\%}$ is the characteristic bending MOE at 18% MC, $E_{measured}$ is the characteristic MOE at the measured MC (N/mm^2) and u is the measured MC (%).

Other Material Properties

Other material properties of timber were computed from the empirical relationships set forth in annex A of EN 338 (2009). These include tensile and compressive strengths parallel and perpendicular to grains, shear strength, shear modulus etc.

The characteristic values of tensile strength parallel to grain, $\rho_{k,12\%}$ and compressive strength parallel to grain, $\rho_{k,18\%}$ were calculated from the following equations 12 and 13 respectively:

$$\rho_{05} \quad (12)$$

$$\bar{\rho} \quad (13)$$

The characteristic values of tensile strength perpendicular to grain, ρ_w and compressive strength perpendicular to grain, kg/m^3 were calculated from the following equations 14 to 17:

ρ_d, for softwoods (14)

kg/m^3, for hardwoods (15)

a, for softwoods (16)

b, for hardwoods (17)

The fractile 5th- percentile MOE parallel to grain $E_{0.05}$ was calculated from equations 18 and 19:

$E_{m,12\%}$, for softwoods (18)

$E_{m,18\%}$, for hardwoods (19)

The characteristic values of mean MOE perpendicular to grain E_i were calculated from the equations 20 and 21:

$E_{90,mean} = E_{0,mean}/30$, for softwoods (20)

$E_{90,mean} = E_{0,mean}/30$, for hardwoods (21)

The characteristic values of mean shear modulus $\bar{E}$, were calculated from equation 22:

$$E_{0,,mean} \quad (22)$$

The characteristic mean density $E_{90,mean}$ was computed from equation 23:

$$E_{m,g} \quad (23)$$

In equations (12) to (23), E_m is the characteristic bending strength, $E_{m,12\%}$ is the characteristic density, $E_{m,18\%}$ is the mean MOE parallel to grain, $E_{90,mean}$ is the mean MOE perpendicular to grain, f_m is the fractile 5th- percentile mean MOE parallel to grain and f_k is the mean shear modulus.

Shear strength, f_m was taken from Table 1 of EN 338 (2009) as specified by the code.

According to Nabade (2012), *Strombosia pustulata, Nauclea diderrichii* and *Entandrophragma cyclindricum* timber species were classified as hardwoods based EN 338 (2009) while *Macrocarpa bequertii* was classified as softwood. For this reason, while using equations 12 to 23, the selected timber species were considered as such.

Results and Discussions

This section of the paper presents the results and discussions of the experimental works carried out on the physical and mechanical properties of the selected timber species. The timber properties considered include MC, density, bending strength and MOE

Results of Moisture Content

The average MC results for the four (4) selected timber species are presented in Table 1.

TABLE 1 SUMMARY OF MC RESULTS

Timber Specie	Measured Moisture Content, (%)		Coefficient of Variation(COV)
	Mean	Standard Deviation	
Strombosia pustulata	23.27	2.98	0.128
Macrocarpa bequertii	24.81	2.21	0.089
Nauclea diderrichii	23.22	2.86	0.123
Entandrophragma cyclindricum	20.06	2.15	0.107

The results of Table 1 show that the mean, standard deviation and coefficient of variation of MC for *Strombosia pustulata, Macrocarpa bequertii, Nauclea diderrichii* and *Entandrophragma cyclindricum* timber species are given by 23.27%, 24.81%, 23.22% and 20.06% respectively with the corresponding coefficients of variation (COV) of 0.128, 0.089, 0.123 and 0.107 respectively. The standard deviations are also given in this order as 2.98, 2.21, 2.86 and 2.15%. The mean values of MC with respect of all the four species were found to fall below the fibre saturation point (FSP). The FSP is usually between 25-30% MC (Nabade, 2012).

Results of Density

Table 2 presents the average values of density for all

the four selected timber species. The mean values, standard deviation, and coefficient of variation for the individual species are also presented in the Table.

TABLE 2 DESCRIPTIVE STATISTICS FOR WET DENSITY

Timber Specie	Timber Density (kg/m³)		Coefficient of Variation (COV)
	Mean	Standard Deviation	
Strombosia pustulata	648.33	34.99	0.054
Macrocarpa bequertii	366.47	27.25	0.074
Nauclea diderrichii	754.67	23.41	0.031
Entandrophragma cyclindricum	542.60	29.06	0.054

The mean values of density ($\bar{\rho}$) for the four species are respectively given by 648.33, 366.47, 754.67 and 542.60 kg/m³ with the corresponding values of standard deviations of 34.99, 27.25, 23.41 and 29.06 kg/m³. Likewise, COVs for densities of slices are respectively in the same order as 0.054, 0.074, 0.031 and 0.054. The two measures of dispersions show a slight variation from the mean values with respect to all species.

The results of the characteristic densities which are the 5-percentile values are given in Table 3. Since the current Nigerian timber design code is based on 18% MC, the values were adjusted to the recommended MC in order to suit the Nigerian environmental condition.

The results given in Table 3 show that characteristic density decreases due to the adjustment of MC from the measured value to 18% MC as computed using equation 3. The decrement was noted with respect to all the four species.

Results of Bending Strength

Table 4 presents the average values of bending strength based on the measured MC and 18% adjusted MC. The adjustment of bending strength values to the equivalent 18% MC was as a result of environmental condition in Nigeria (NCP2, 1973).

The results of characteristic bending strengths presented in Table 4 show that characteristic bending strength increased as MCs were adjusted to 18% with respect to all the species and this can be attributed to moisture migration. For instance, the bending strength for *Strombosia pustulata* at the measured MC corresponding to four point bending test was 44.9 N/mm². The adjusted values of bending strength to 18% MC increased to 52.0 N/mm². According to equation 7, characteristic bending strength increases for any value of MC above 18%. This is because the denominator of equation 7 is less than unity when MC is greater than 18%. For all the species considered, MCs are greater than 18%. This also applies to other strength properties such as tensile and compression parallel and perpendicular to grains. Also it can be observed that the three point bending test results gave higher bending strengths than the corresponding four point test for all the species. This is explained by the simply supported beam theory carrying three and four point loads respectively as presented.

TABLE 3 RESULTS OF CHARACTERISTIC VALUES OF DENSITY

Timber Specie/Property		*Strombosia Pustulata*	*Macrocarpa bequaertii*	*Nauclea diderrichii*	*Entandrophragma cyclindricum*
Density (kg/m³)	ρ_k	590.60	321.51	716.04	494.65
	$\rho_{k,18\%}$	575	311	697	490

TABLE 4 RESULTS OF CHARACTERISTIC VALUES OF BENDING STRENGTH

Timber Property	*Strombosia Pustulata*		*Macrocarpa bequaertii*		*Nauclea Diderrichii*		*Entandrophragm cyclindricum*	
	4 pt.	3 pt.	4 pt.	3 pt.	4 pt.	3 pt.	4 pt.	3 pt.
$f_{m,k}$ (N/mm²)	44.9	50.6	19.0	25.7	36.4	42.1	31.1	40.0
$f_{m,18\%}$ (N/mm²)	52.0	59.9	23.8	32.2	43.1	49.7	33.1	42.5

TABLE 5 RESULTS OF CHARACTERISTIC VALUES OF MOE

Timber Property	*Strombosia pustulata*		*Macrocarpa bequaertii*		*Nauclea diderrichii*		*Entandrophragm cyclindricum*	
	4 pt.	3 pt.	4 pt.	3 pt.	4 pt.	3 pt.	4 pt.	3 pt.
$E_{m,k}$ (KN/mm²)	10.10	12.5	6.67	6.68	9.28	11.11	8.50	9.92
$E_{m,18\%}$ (KN/m²)	10.9	13.5	7.39	7.40	10.0	12.00	8.76	10.22

TABLE 6 ADJUSTED CHARACTERISTIC VALUES OF MATERIAL PROPERTIES TO 18% Mc

Timber Specie	Density (Kg/m³)	Modulus of Elasticity (kN/mm²)		Bending Strength (N/mm²)	
		4 Point. Bending	3 Point. Bending	4 Point. Bending	3 Point. Bending
Strombosia Pustulata	575	10.925	13.471	51.97	59.91
Macrocarpa Bequaertii	311	7.392	7.401	23.80	32.20
Nauclea Diderrichii	697	10.029	12.001	43.06	49.73
Entandrophragma Cyclindricum	490	8.757	10.219	33.12	42.51

TABLE 7 RESULTS OF CHARACTERISTIC VALUES OF OTHER MATERIAL PROPERTIES BASED ON 18% MC

Other Material Properties	Timber Specie			
	Strombosia pustulata	*Macrocarpa bequertii*	*Nauclea diderrichii*	*Entandrophragma Cyclindricum*
Tension Parallel $f_{t,0,k}$ ((N/mm²)	31.18	14.28	25.84	19.87
Tension Perpendicular $f_{t,90,k}$ ((N/mm²)	0.6	0.4	0.6	0.6
Compression Parallel $f_{,c,0,k}$ ((N/mm²)	29.58	20.82	27.18	24.16
Compression Perpendicular $f_{,c,90,k}$ ((N/mm²)	8.63	2.18	10.46	7.35
Shear Strength $f_{v,k}$ ((N/mm²)	4.0	3.0	4.0	4.0
5% MOE Parallel $E_{0,05}$ ((KN/mm²)	9.18	4.95	8.42	7.36
Mean MOE Perpendicular $E_{90,mean}$ ((KN/mm²)	0.73	0.25	0.67	0.58
Mean Shear Modulus G_{mean} (K(N/mm²)	0.68	0.46	0.63	0.55
Mean Density ρ_{mean} (kg/m^3)	690	373	838	588

TABLE 8 SUMMARY OF RESULTS OF PHYSICAL AND MECHANICAL PROPERTIES OF SELECTED TIMBERS

Timber Specie	*Strombosia Pustulata*	*Macrocarpa*	*Nauclea Diderrichii*	*Entandrophragma Cyclindricum*
No. of specimens for bending & MOE/MC	40/15	40/15	40/15	40/15
Measured MC (%)	23.27	24.81	23.22	20.06
Char. Density @ measured MC	590.60	321.31	716.04	494.65
Adj. Char. Density to 18% MC	575	311	697	490
3 pt. Char. Bending strength	50.6	25.7	42.1	40.0
4 pt. Char. Bending strength	44.9	19.0	36.4	31.1
Adj. 3 pt. Char. Bending strength to 18% MC	59.91	32.20	49.73	42.51
Adj. 4 pt. Char. Bending strength to 18% MC	51.97	23.80	43.06	33.12
3 pt. Char. MOE	12.50	6.88	11.11	9.92
4 pt. Char. MOE	10.00	6.67	9.28	8.50
Adj. 3 pt. Char. MOE to 18% MC	13.471	7.410	12.001	10.219
Adj. 4 pt. Char. MOE to 18% MC	10.925	7.392	10.029	8.357
Tension parallel	31.18	14.28	25.84	19.87
Tension perp.	0.6	0.4	0.6	0.6
Compression parallel	29.58	20.82	27.18	24.16
Compression perp.	8.63	2.18	10.46	7.35
Shear strength	4.0	3.0	4.0	4.0
5% MOE parallel	9.18	4.95	8.42	7.36
Mean MOE perp.	0.73	0.25	0.67	0.58
Mean shear modulus	0.68	0.46	0.63	0.55
Measured Mean density	690	373	838	588

MOE in Bending

The results of characteristic MOE in bending presented in Table 5 show that characteristic MOE increased as the MCs were adjusted to 18% with respect to all the species considered. For the same reason as for equation 7; the values of characteristic MOE computed using equation 11 increase when MC is greater than 18%. This also implies that timber attains its greatest stiffness when approaching dryness. This also applies to other stiffness properties such as mean MOE perpendicular, 5% MOE, shear modulus

etc (Nabade, 2012).

For ease of reference, Table 6 gives the average values of material properties of the selected timber species as adjusted to 18% MC.

The results presented in Table 6 showed that *Nauclea diderrichii* was found to have the highest density value of 697 Kg/m^3 followed by *Strombosia pustulata* with 575 Kg/m^3, followed by *Entandrophragma cyclindricum* with 490 Kg/m^3 and the least value of 311 Kg/m^3 corresponding to *Macrocarpa bequaertii*. The results also show that for the four selected timber species, decrease in the value of strength and stiffness properties is in this order: *Strombosia pustulata*, *Nauclea diderrichii*, *Entandrophragma cyclindricum*, Macrocarpa *bequaertii*.

Other Material Properties based on 18% MC

The results of other material properties of the timber species computed from the empirical relationships given in EN 338 (2009) are as presented in Table 7. In the determination of these material properties, only the minimum values of strength and stiffness properties were considered in the computations (EN 384, 2004). However, for the all cases, the minimum values correspond to those obtained from the four point bending test.

Also, the material properties given in Table 7 were adjusted to the 18% MC in order to suit the Nigerian environmental condition.

Table 8 presents the summary of the results of both the physical and mechanical properties of the four timber species as recommended by EN 384 (2004). The characteristic values of the reference and other properties as computed based on the measured MCs and as adjusted to 18% MC were presented.

Conclusions

Laboratory experiments were conducted to determine the physical and mechanical properties of four Nigerian timber species, namely: *Strombosia pustulata, Macrocarpa bequaertii, Nauclea diderrichii* and *Entandrophragma cyclindricum*, in accordance with EN 13183-1 (2002), EN 408 (2003) and ASTM D193 (2000). The mechanical properties were determined using three point and four point bending tests. The characteristic values of the material properties were obtained in accordance with EN 384 (2004).

The results of the characteristic values of the reference material properties were adjusted based on 18% MC. The adjustments on the properties were carried out to satisfy Nigerian environmental condition for design of timber structures using the limit state requirements.

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